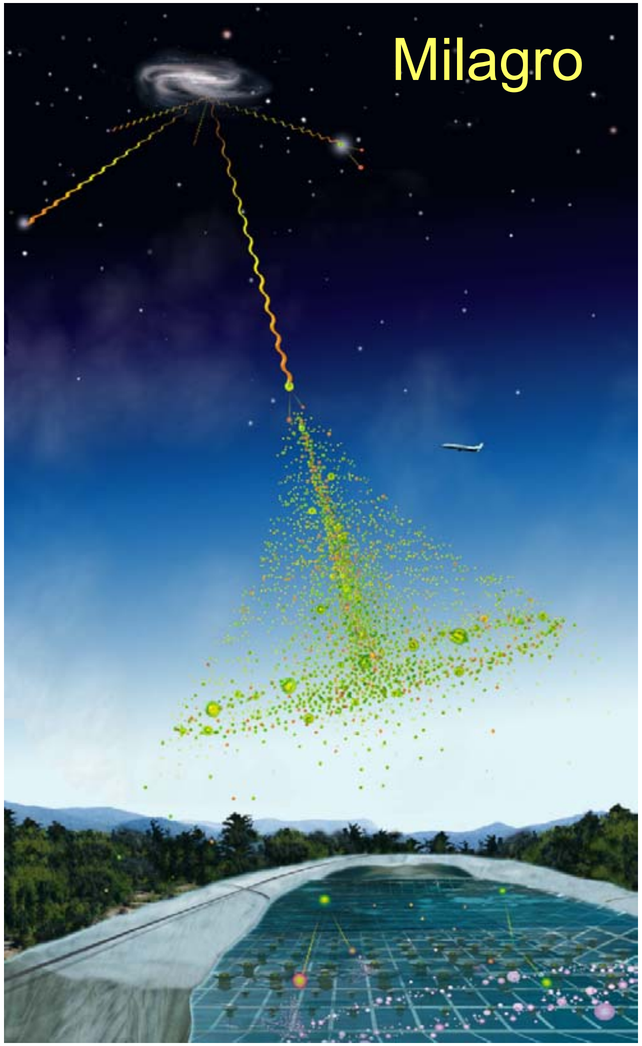
# Cosmology with High Energy Gamma Rays





Brenda Dingus
P-23

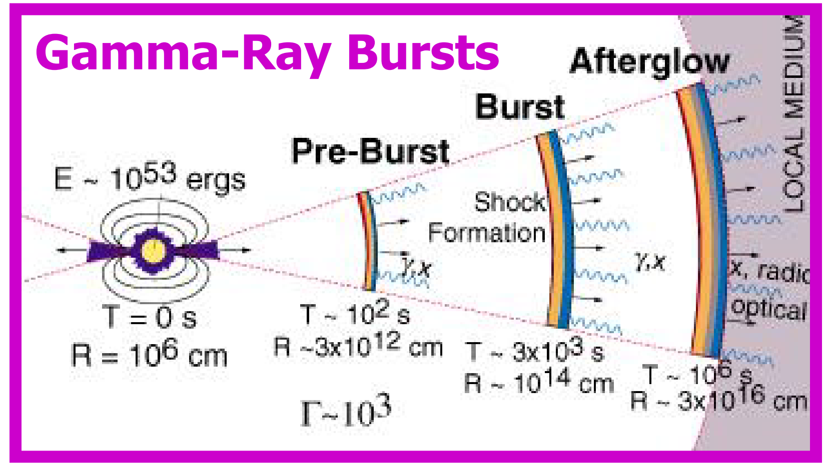
Gamma-Ray Production
- Particle Accelerators
- WIMPs
- Primordial Black Holes

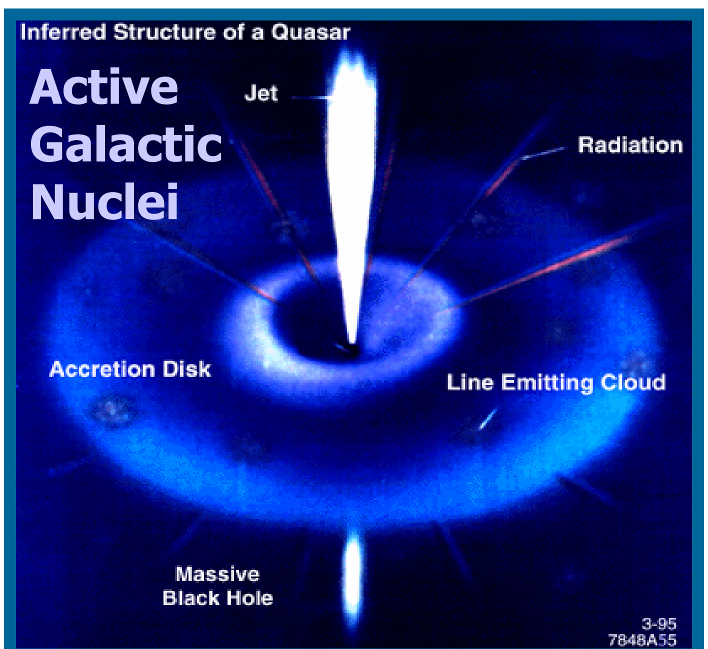
Gamma-Ray Interactions
- Galaxy & Star Formation
- Quantum Gravity

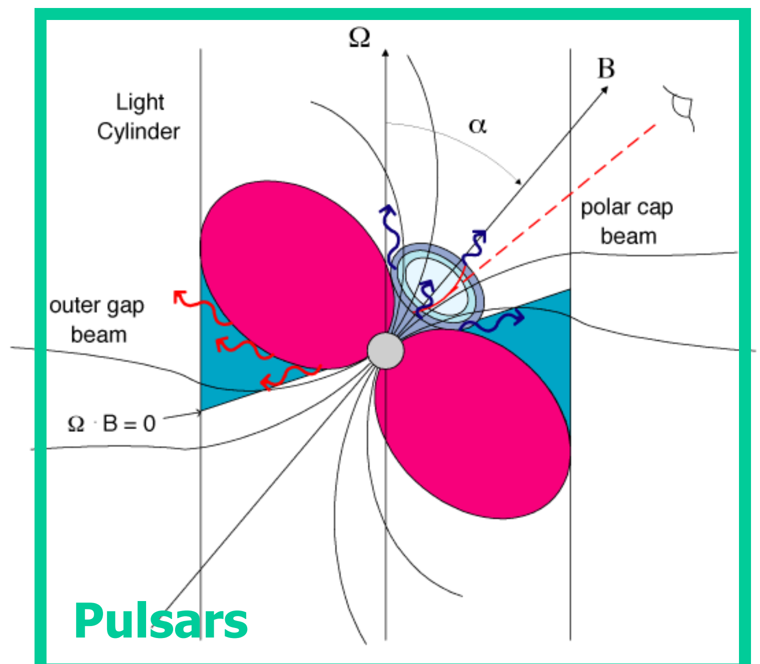
# γ-ray Production via Particle Acceleration

## Astrophysics

- Particles accelerated to relativistic energies in jets
- Gamma rays produced by
  - Electrons Inverse Compton scattering ambient photons
  - Proton cascades

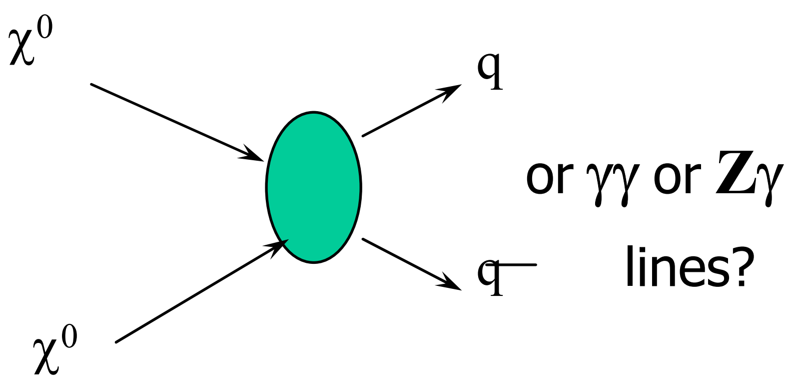


# $\gamma$-ray Production via Annihilations (WIMPs)

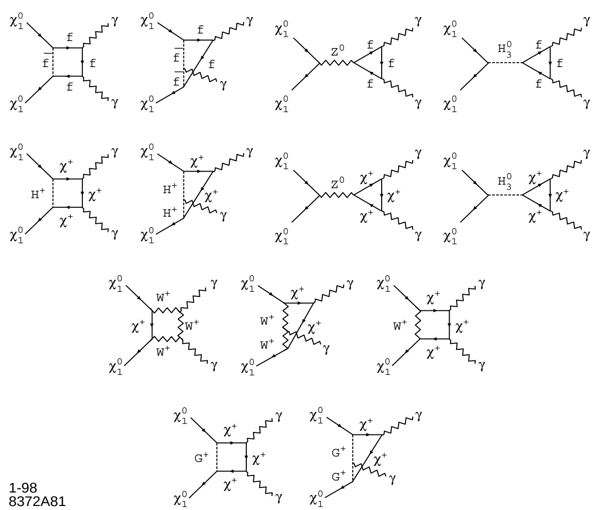
- WIMP dark matter candidate, the neutralino $\chi^0$ , is the lightest supersymmetric particle in R-parity conserving SUSY.
- The $\chi^0$ is it's own antiparticle and will annihilate to produce $\gamma$-rays.
- The mass of the neutralino, $M\chi^0$, is constrained to be greater than ~30 GeV, but less than a few TeV.
- The annihilation produces a continuum of gamma-rays peaking at ~0.05 $M\chi^0$ and gamma-ray lines at $M\chi^0$



# $\gamma$-rays from WIMP Annihilation

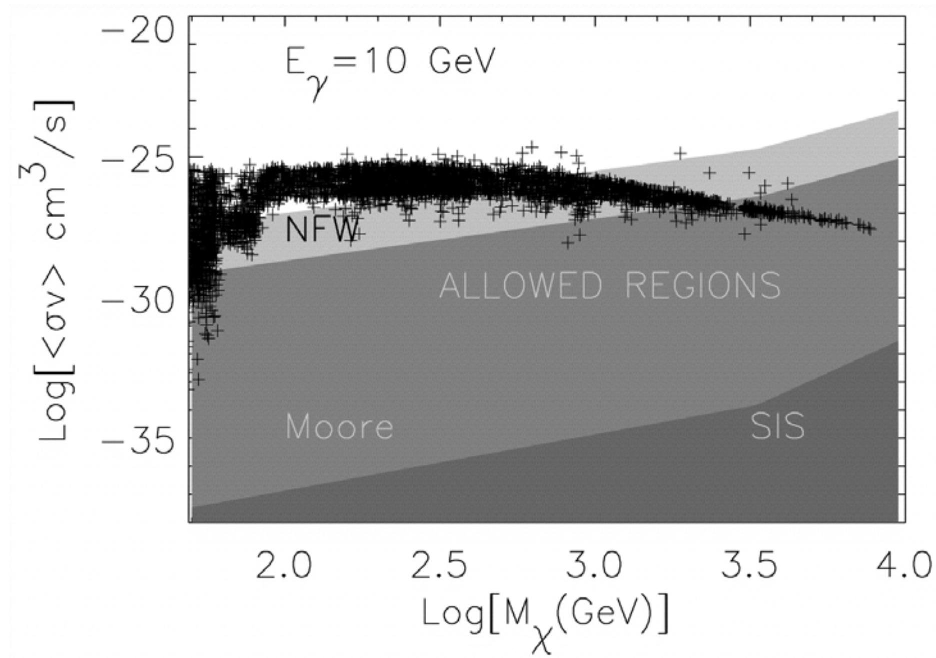
Flux of $\gamma$-rays depends on SUSY parameters which are not well constrained

$\chi\ \chi \rightarrow \gamma\gamma$




Bergström & Ullio 1997;
Bern et al. 1997

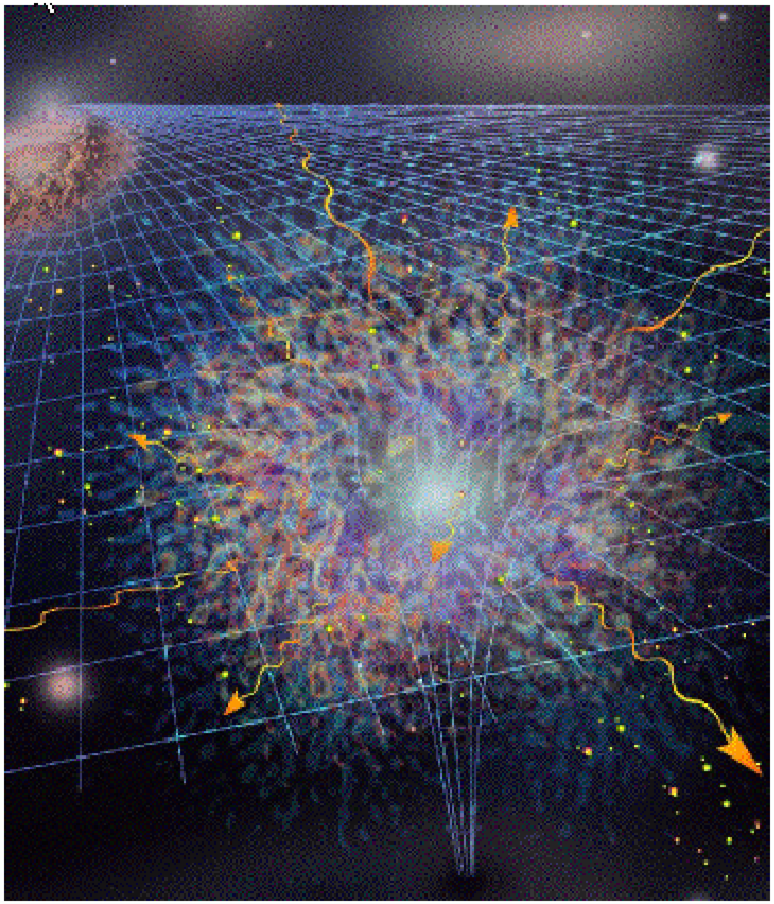
Flux of $\gamma$-rays depends on clumping of WIMPs as the # density squared




Aloisio, Blasi, & Olinto, 2004 place upper limits from 10 GeV high latitude diffuse flux

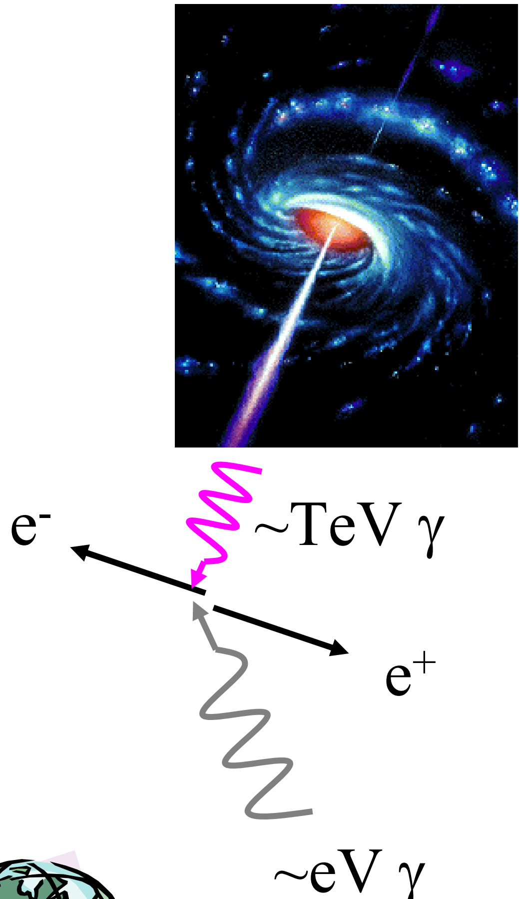
# Thermal γ-ray Production (Primordial Black Holes)

- Primordial density perturbations may have lead to the gravitational collapse of mass into primordial black holes (PBHs).
- PBHs will then emit Hawking radiation causing the mass of the PBH to decrease.
- PBHs radiate thermally with a temperature inversely proportional to its mass.
- Thus, the higher the temperature, the lower the mass, and the shorter the lifetime.
- Eventually the temperature is high enough to emit elementary particles (which produce gamma-rays) and the PBH evaporates.
- The gamma-ray light curve and spectrum depend on whether a quark gluon photosphere is created. The theorists are arguing about this.
- Current limits are ~ 1 PBH evaporation /pc$^3$/year based on the gamma-ray diffuse emission and no candidate evaporations have been observed.



Visualization of PBH 1s before evaporation: Rs = 1 μfermi; white = 10 TeV; red = 1 TeV.
Computer image by Aurore Simonnet, (UCSC) © 2000

# $\gamma$-ray Attenuation probes Star Formation

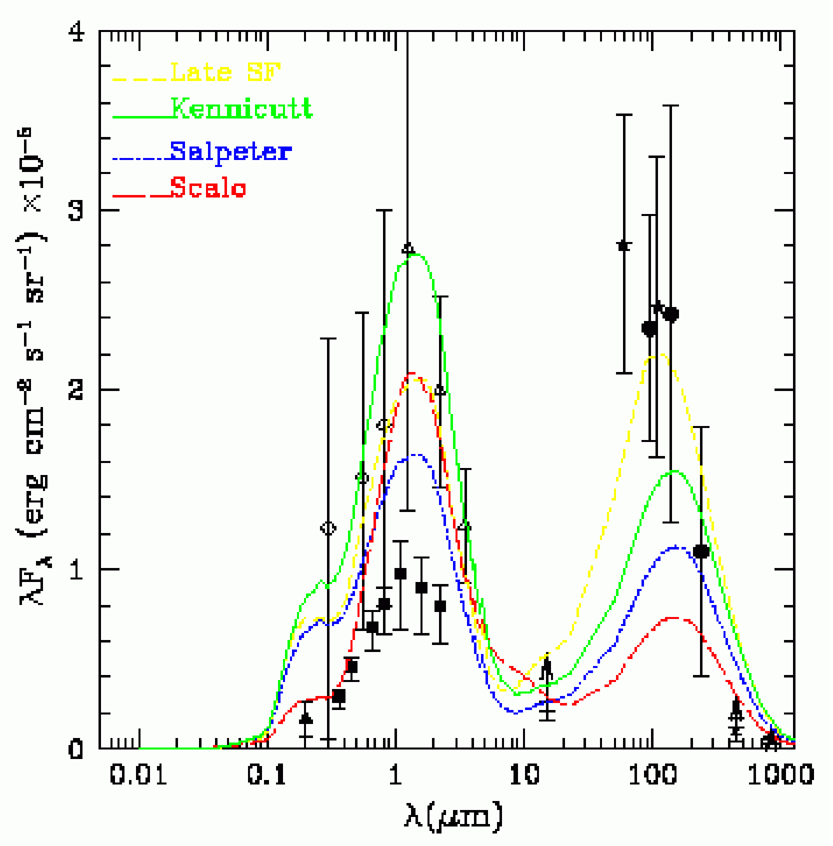


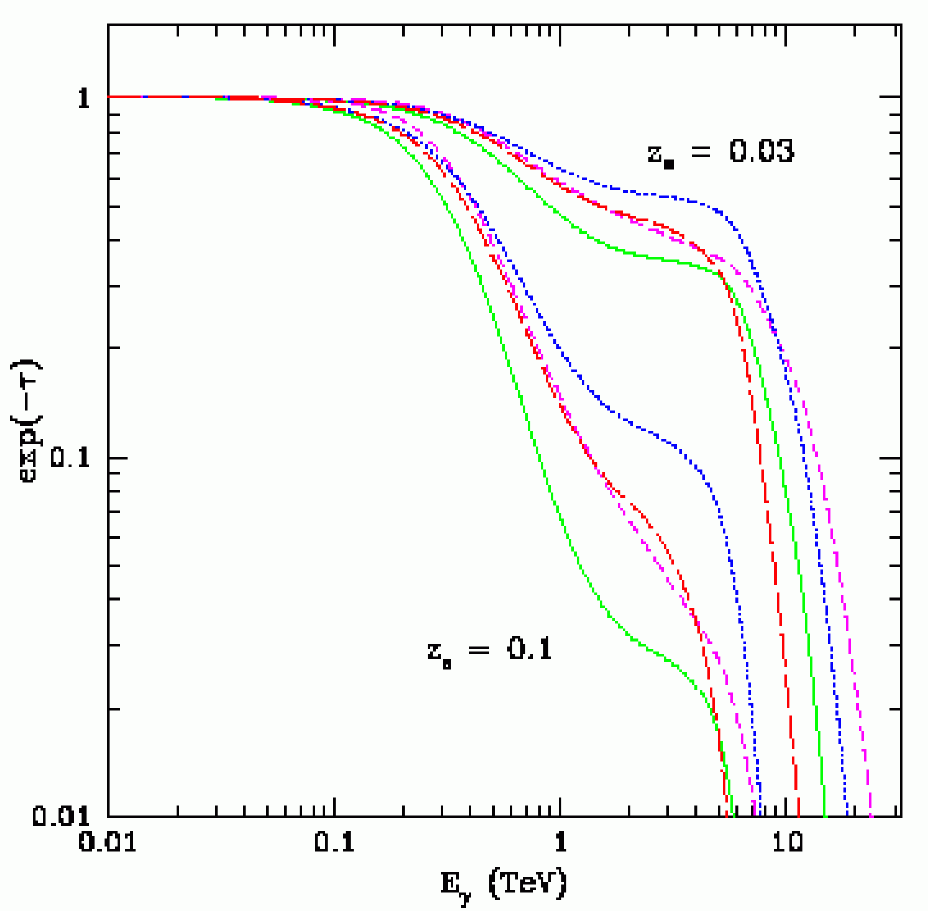

- TeV Gamma-Rays produce electron-positron pairs when interacting with IR-optical photons
- The extragalactic background light (EBL) of IR-optical photons cannot be measured directly due to the foreground of our Galaxy
- The EBL is produced by dust heated by early stars, thus the EBL probes star and galaxy formation, e.g. the initial mass function of stars and the star formation rate vs redshift
- Observations of the attenuation of TeV energy spectra for sources at different redshifts will constrain the EBL.

# IR-optical background effects $\gamma$-ray Spectra

Different initial mass function models fit the direct observations of the IR-optical extragalactic background light (EBL).

(Primack, 2002)




TeV spectral measurements of attenuation for a source at two different redshifts (z=0.03 and z=0.10) will help measure the EBL flux

# $\gamma$-rays test Quantum Gravity Predictions

- Many theories of quantum gravity predict that the speed of light depends on the energy of the photons. (Amelino-Camelia 1998, Ellis 2000)

$$v_\gamma = c(1 - E_\gamma/E_{QG} - O[(E_\gamma/E_{QG})^2])$$

where $E_{QG}$ is of order the Planck mass $\sim 10^{19}\ GeV$

- This "Lorentz invariance" is testable by measuring the difference in arrival time of gamma-rays from a transient event at a very large distance, i.e. gamma-ray bursts.

$$\Delta t = (L/c)(\ \eta\, E_\gamma/E_{QG}) \sim 40\ sec\ \eta\ \boldsymbol{z}\, E_{TeV}$$

- For $\Delta t$ = 1 sec , z = 0.25 , and $E_\gamma$ = 100 GeV , we are probing $\eta \sim 1$.

- Gamma-ray bursts show msec variability and are located at $z \sim 1$.

# Conclusion

- **Gamma-ray astronomy is opening a new window on the Universe**
- **Gamma rays are unique tools to study various cosmological effects**
- **Future holds promise with new improved $\gamma$-ray observatories**

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|---|---|---|
| **GLAST** | **Large field of view satellite** | **Launch 2007** |
| **VERITAS** | **Air Cherenkov Telescope** | **Fully Operational 2006** |
| **HESS** | **Air Cherenkov Telescope** | **Beginning operations** |
| **MAGIC** | **Air Cherenkov Telescope** | **Mostly constructed** |
| **CANGAROO** | **Air Cherenkov Telescope** | **Being Upgraded** |
| **HAWC** | **Large field of view air shower detector** | **Planning begins** |